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REVIEW ARTICLE

Intramedullary nail versus volar locking plate fixation for the treatment of extra-articular or simple intra-articular distal radius fractures: systematic review and meta-analysis

Bing Zhang[1,2] · Hengrui Chang[1,2,3] · Kunlun Yu[1,2] · Jiangbo Bai[1,2] · Dehu Tian[1,2] · Guisheng Zhang[1,2] · Xinzhong Shao[1,2] · Yingze Zhang[1,2,3]

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Abstract

Aims This study aims to compare the outcomes of intramedullary nail (IMN) and volar locking plate (VLP) fixation for treatment of extra-articular or simple intra-articular distal radius fractures.

Methods PubMed, Embase, Medline and Cochrane Collaboration Central databases were searched for studies that compared the results of IMN and VLP fixation for the treatment of distal radius fractures up to March 2016. Stata 11.0 was used to perform the meta-analysis.

Results Six randomized controlled trials (RCT) and two retrospective studies were included in this review, including 463 patients. No significant differences were found between two treatment methods in terms of any functional score, radiographic parameters and motion range in the late postoperative period (6, 12 and 24 months). However, IMN did better than VLP at the post-operative six weeks and three months, no matter which functional scoring system was used. The incidence of carpal tunnel syndrome (CTS) was 8.7% in the VLP group, significantly higher than that (0.8%) in the IMN group (OR, 0.183; 95%CI, 0.045–0.74). But for other complications, such as infection (OR, 0.449; 95%CI, 0.095–2.114), tendious damage (OR, 0.931; 95%CI, 0.238–3.648), tenosynovitis (OR, 0.806; 95%CI, 0.209–3.108), algodystrophy (pain) (OR, 0.795; 95%CI, 0.291–2.173) and radial nerve paraesthesia (OR, 1.8143; 95%CI, 0.834–3.942), no significant differences were found ($P > 0.05$).

Conclusions Compared to VLP, IMN could provide better early postoperative functional outcomes and reduce the incidence of carpal tunnel syndrome, which could be of particular help in restoring confidence for workers with specialized man-

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✉ Yingze Zhang
drzhang2013@126.com

Bing Zhang
drzhangbing2013@126.com

Hengrui Chang
18831178786@163.com

Kunlun Yu
drkunlunyu2013@163.com

Jiangbo Bai
drjiangbobai2013@163.com

Dehu Tian
drdehutian2013@163.com

Guisheng Zhang
drguisheng2013@163.com

Xinzhong Shao
drxinzhong2013@163.com

[1] Department of Orthopaedic Surgery, The Third Hospital of Hebei Medical University, NO. 139 Ziqiang Road, Shijiazhuang, Hebei 050051, People's Republic of China

[2] Department of Hand Surgery, The Third Hospital of Hebei Medical University, Shijiazhuang, Hebei 050051, People's Republic of China

[3] Key Laboratory of Biomechanics of Hebei Province, Shijiazhuang, Hebei 050051, People's Republic of China

ual skills to return to their prior jobs. Additionally, the conclusion should be cautiously treated, because it was reached in the context of limited amount of studies and relatively small sample size. Therefore, future studies with good design and large samples are required to verify this conclusion.

Keywords Meta-analysis · Distal radius fracture · Intramedullary nailing · Volar-locking plate

Introduction

Distal radius fractures are commonly seen skeletal injuries, accounting for 11–16.7% of all fractures in adults in orthopaedic departments [1–3]. The incidence of distal radius fracture varies with age, and is characterized by bimodal distribution in 16–20-year-old males and 56–60-year-old females [2, 3]. Of the distal radius fractures, over 40% were unstable fractures, presenting a great challenge for surgeons [4]. Surgeons should take both fracture severity and patients' functional requirements into consideration to develop an optimal treatment strategy and try to decrease the risk of post-operative complications.

Restoration of articular surface, stable fixation and early wrist motion are crucial factors in the treatment of unstable distal radius fractures. Closed reduction and casting immobilization was the traditional treatment choice of distal radius fractures but was associated with post-operative reduction loss and subsequent high incidence of malunion [5, 6]. Improved functional results and reduced complications have been demonstrated by several common fixation methods, such as percutaneous Kirschner wire fixation, external fixation with bridging fixators (BrEF) or nonbridging fixators (non-BrEF) and open reduction and internal fixation with dorsal or volar plate [7–10]. With the advent of the volar-locking plate (VLP) system, open reduction and internal fixation with such a plate has become increasingly popular since it could provide similar stability as dorsal plates, and significantly reduce tendon problems [11–13]. However, extensive dissection of soft tissue around the fracture zone compromises the biological environment for fracture healing and increases the risk of non-union or malunion. The incidence of overall complications was still reported as 9.7–15%, in which tendon problems and complex regional pain syndrome (CRPS) accounted for the most [14–17].

As the alternative to the volar plates, intramedullary devices have been introduced for stabilization of unstable distal radius fractures. Because of the minimal soft tissue disruption and low profile, intramedullary nailing (IMN) was reported to have unique advantages in reducing soft tissue-related complications [18]. Recent systematic reviews have reported clinical outcomes of IMN devices for treatment of unstable distal radius fractures, but failed to compare this technique with VLP fixation [18, 19]. Wang et al. firstly conducted a meta-analysis of RCTs with the aim to evaluate the clinical, radiographic outcomes and complications between both fixations, but failed to reach definitive conclusions [20]. Although designed as a meta-analysis including high-quality RCTs, it was limited by insufficient samples. Meanwhile, from our clinical practice and reports from literature, we speculate IMN could provide better early outcomes than VLP, which might be neglected in his study.

Given that, we conducted this systematic review and meta-analysis to determine whether IMN or VLP fixation is more advantageous for management of extra-articular or simple intra-articular distal radius fractures. The primary outcomes were functional scores including disability of arm, shoulder and hand (DASH), visual analogue scale (VAS), Gartland and Werley score, Mayo score and Castaing score at different post-operative follow-ups. The secondary outcomes were radiographic parameters, motion ranges and associated complications.

Materials and methods

Search strategy

A computerized search of PubMed, Embase, Medline and Cochrane Collaboration Central databases was performed up to March 2016. The following keywords and combinations were used: "distal radius fracture" or "distal radial fracture" AND "volar plate" AND "intramedullary" or "percutaneous osteosynthesis". Two investigators (Zhang B and Chang HR) independently evaluated the titles and abstracts of the candidate papers. Full-text articles without language restriction could be included in this meta-analysis. Additional literature were manually searched from the reference lists of identified original articles or reviews.

Inclusion criteria and exclusion criteria

We included the studies that met the following criteria: (1) published original studies which were randomized controlled trials (RCTs), cohort studies, prospective or retrospective comparative studies, (2) participants were 18 years and older, (3) patients with extra or simple intra-articular distal radius fractures were allocated into two treatment groups: (a) IMN fixation group and (b) VLP fixation group, and (4) studies could provide at least one of the following clinical outcomes: (a) functional score with common functional systems, (b) range of motion, (c) radiographic parameters, (d) post-operative complications. Exclusion criteria were: (1) case reports, reviews and conference reports, (2) biomechanical or cadaveric researches, and (3) any pathological or metabolic fractures or open fractures.

Data extraction

Two co-authors (Zhang B and Chang HR) identified the appropriate studies according to the inclusion criteria and extracted relevant data independently. The following data were extracted: (1) basic characteristics of studies (the name of the first author, year of publication and the type of studies), (2) general characteristics of participants (gender, age and duration of follow-up), (3) functional outcome measures (DASH, VAS, Gartland and Werley score, Mayo score and Castaing Score, wrist flexion and extension, radial and ulnar deviation, forearm pronation and supination etc), (4) radiological results (radial inclination, radial height, volar tilt and ulnar variance), and (5) postoperative complications (tendinous damage, tenosynovitis, algodystrophy, carpal tunnel syndromes and radial nerve paraesthesia, etc.). A third author (Zhang Y) would make the final decision if there was any disagreement between them.

Quality assessment

Because both RCTs and non-RCTS were included, we did not apply the Jadad scoring system, which is designed only for RCTs. We used a standardized electronic form of 17 predefined criteria from the Consort statement [21], which was used in previous reviews or meta-analyses [22, 23] to solve similar problems. Two investigators (Zhang B and Chang HR) independently graded each article, adding one point when one criterion was met; otherwise, no score was awarded. Finally, the total points of each paper were calculated and controversial scores were solved by discussion between both investigators.

Statistical analysis

Meta-analysis for every variable was performed using the Stata software, version 11.0 (Stata Corporation, College Station, TX, USA). For dichotomous variables, results were summarized with odds radios (ORs) and a 95% confidence interval (95%CI). For continuous variables, outcomes were summarized with standardized mean difference (SMD) and 95% CI. A significant difference was considered when $P < 0.05$. Heterogeneity among studies was qualitatively tested by Q-test and quantitatively tested by I^2 statistics [24]. A $P < 0.10$ was considered as significant and an $I^2 > 50\%$ was considered as high heterogeneity. A random-effects model was applied when heterogeneity was detected or the statistical heterogeneity was high ($P < 0.10$ or $I^2 > 50\%$). Otherwise, a fixed-effects model was used ($P \geq 0.10$ or $I^2 \leq 50\%$) [23]. The results were summarized graphically using a forest plot or were listed in the tables. Furthermore, to explore sources of heterogeneity, sensitivity analysis was performed based on the following factors: methodological quality and width of the confidence interval.

Results

Study search, selection and quality assessment

A total of 587 researches were initially retrieved. After strict inclusion and exclusion criteria, eight studies were finally included in this meta-analysis. Of them, seven were published in English and one in German and published from 2009 to 2015. Six studies were designed as RCTs and two as retrospective comparative studies. There were 221 participants in the IMN group and 242 in the VLP group, and 76.7% of them (355 cases) were female. Detailed information about these studies and participants is shown in Table 1. The flowchart which indicated the progress of literature selection was presented in Fig. 1.

The score for quality assessment was 13.6 ± 2.0 (range, 11–16). The detailed outcomes of quality assessment for these studies were as follows: 11 points in two studies [25, 26]; 13 in two [27, 28]; 14 in one [29], 15 in one [30] and 16 in two studies [31, 32].

Table 1 Detailed information on the basic characteristics of the eight included studies and participants

First author	Year	Country	Study design	IM	VLP	Age (years), IM/VLP	Gender (F/M)	Dominant side	Follow-up (months)
Chappuis	2011	Belgium	RCT	16	15	71.7/71.7	27/4	16/15	6
Safi	2013	Czech	RCT	31	31	55/59	49/13	38/24	12
Gradl	2013	Germany	RCT	66	55	63.1/61.4	103/18	56/55	24
Plate	2015	USA	RCT	30	30	54.7/54.6	44/16	NA	24
Aita	2014	Brazil	RCT	16	16	36.8/33.1	17/15	16/16	12
Zehir	2014	Turkey	RCT	31	33	47.9/45.6	52/12	29/35	9.0–19
Lerch	2009	Germany	Retrospect	13	12	60/57	19/6	NA	1.9–11.6
Vlček	2013	Czech	Retrospect	18	50	61/48.5	51/17	33/35	12

IM intramedullary fixation, *VLP* volar locking plating, *M* male, *F* female, *NA* not available

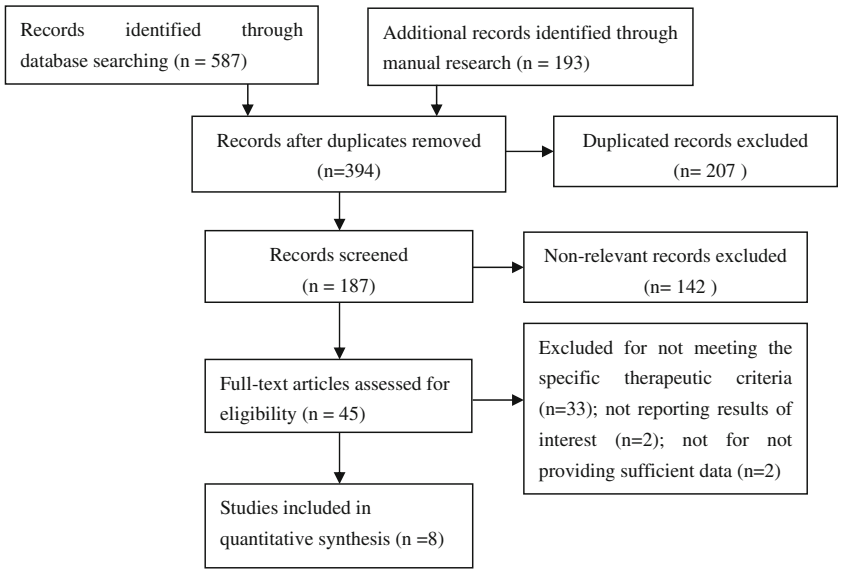


Fig. 1 Flow diagram of literature search

Functional outcomes

As detailed in Table 2, at the post-operative six weeks and three months, IMN did better than the VLP groups, regardless of which function scoring system was used.

At the post-operative six, 12 and 24 months, no significant differences were found except for the Mayo wrist score at post-operative six months [28]. In this study, Chappuis et al. found a significantly worse Mayo score in the IMN than the VLP group at the six-month follow up (65 versus 85.6) [28]. The detailed results are presented in Table 2.

For most variables, only one study could provide data of standard format for statistical analysis. For DASH and Gartland and Werley score at 12-months, two studies provided sufficient data for calculation of standardized mean differences (SMD). However, no significant differences were found in the context of non-significant heterogeneity, while I^2 statistics were 35.6% and 15.7%, respectively.

Table 2 Summary of the outcomes of function scores

Variable	Number of studies	First author	IM cases	Mean	SD	VLP cases	Mean	SD	*P*
DASH (6 weeks)	1	Safi	31	21	16.2	31	38	18.3	<0.001
DASH (3 months)	1	Safi	31	9	11.3	31	18	12.6	0.004
DASH (6 months)	1	Chappuis	16	22.9	20.9	15	20.6	20.3	0.89
DASH (12 months)	2	Safi	31	4	9.5	31	6	9.9	0.961
		Vlček	18	12.12	8.48	50	10.05	7.71	
GW score (6 months)	1	Lerch	13	6.9		12	6.5		0.885
GW score (12 months)	2	Zehir	31	1.77	0.84	33	1.64	0.82	
		Vlček	18	4.44	3.73	50	5.86	6.24	
GW score (24 months)	1	Gradl	66	2.3	2.3	55	2.7	3.3	0.434
VAS at rest (24 months)	1	Gradl	66	0.2	0.9	55	0.2	0.7	1
VAS at activity (24 months)	1	Gradl	66	0.8	1.5	55	1	2	0.53
Mayo score (6 weeks)	1	Safi	31	77	15.1	31	53	17.5	<0.001
Mayo score (3 months)	1	Safi	31	91	11.3	31	80	13	0.001
Mayo score (6 months)	1	Chappuis	16	65	13.4	15	85.6	19.2	0.002
Mayo score (12 months)	1	Safi	31	95	9.2	31	92	10.1	0.224
Castaing Score (12 months)	1	Vlček	18	6.22	5.82	50	5.26	4.22	0.457
Castaing Score (24 months)	1	Gradl	66	1.7	1.1	55	2.3	2.5	0.081

GW score Gartland and Werley score, *IM* imtramedullary fixation, *VLP* volar locking plate, *SD* standard deviation, *DASH* disability of arm, shoulder and hand, *VAS* visual analogue scale, *NA* not available

Radiographic measurements and motion range

Several studies could provide data of standard format for calculating the SMD, and these data values were all measured at the post-operative 12 and 24-month follow up [25, 29–32]. As shown in Table 3, no significant differences were found in terms of any variable. However, for radial inclination, radial height, ulnar variance, ulnar deviation, supination and pronation at 12-month post-operative follow up, there was significant heterogeneity. After sensitivity analysis, the significance did not alter and the results are summarized in Supplementary Table 1.

Complications

Complications including infection, tendinous damage, tenosynovitis, algodystrophy (pain) and radial nerve paraesthesia were reported. However, there were no significant differences observed for any variable and the heterogeneity among studies was very low ($I^2 = 0$ or 16%). The only variable that presented as significant was carpal tunnel syndrome (CTS), which was more likely to occur in the VLP group ($P = 0.017$). The incidence of CTS was 8.7% (10/115) in the VLP group, significantly higher than that in the IMN group (0.8%, 1/126) without any heterogeneity ($I^2 = 0$). Results of meta-analysis are presented in the forest plots and Table 3 (Fig. 2).

Discussion

The VLP system has gained widespread use for treatment of distal radius fractures. The advent and application of IMN was supposed to have similar or even better results than VLP, but this conclusion has not been verified by sufficient evidence. In this meta-analysis, we reviewed 587 potential citations from the four commonly used large databases to evaluate the functional outcomes, radiographic parameters, motion range of the wrist and complications between the IMN and VLP fixations for treatment of extra-

Table 3 Summary of the outcomes of radiographs, motion range and complications

Variables	Number of studies	Pooled OR or SMD	LL 95% CI	UL 95% CI	*P*-value	Q-test (*P*) for heterogeneity	[c]I^2 (%)
Radiograph measurements							
Radial inclination(12 months)	3	−0.451	−1.363	0.461	0.332 [b]	0	88.9
Radial height (12 months)	3	−0.195	−0.688	0.298	0.438 [b]	0.063	63.9
Volar tilt (12 months)	3	0.015	−0.278	0.308	0.92[a]	0.791	0
Ulnar variance (12 months)	2	0.662	−0.717	2.04	0.347 [b]	0	92.2
Volar tilt (24 months)	2	0.082	−0.212	0.375	0.586	0.205	37.7
Ulnar variance (24 months)	2	0.000	−0.293	0.293	1 [a]	1	0
Motion range							
Flextion (12 months)	3	0.168	−0.127	0.462	0.264 [a]	0.396	0
Extension (12 months)	3	−0.103	−0.398	0.191	0.492 [a]	0.194	39.2
Radial deviation (12 months)	3	0.020	−0.329	0.37	0.91 [a]	0.567	0
Ulnar deviation (12 months)	3	−0.563	−1.464	0.338	0.221 [b]	0	88.6
Supination (12 months)	3	−0.074	−0.548	0.4	0.761 [b]	0.077	61.1
Pronation (12 months)	3	−0.057	−0.804	0.69	0.882 [b]	0.002	84.0
Complication							
Infection	2	0.449	0.095	2.114	0.311 [a]	0.816	0
CNS	4	0.183	0.045	0.741	0.017 [a]	0.988	0
Tendious damage	4	0.931	0.238	3.648	0.919 [a]	0.547	0
Tenosynovitis	3	0.806	0.209	3.108	0.754 [a]	0.53	0
Algodystrophy (pain)	5	0.795	0.291	2.173	0.655 [a]	0.614	0
RNP	6	1.814	0.834	3.942	0.133 [a]	0.311	16.0

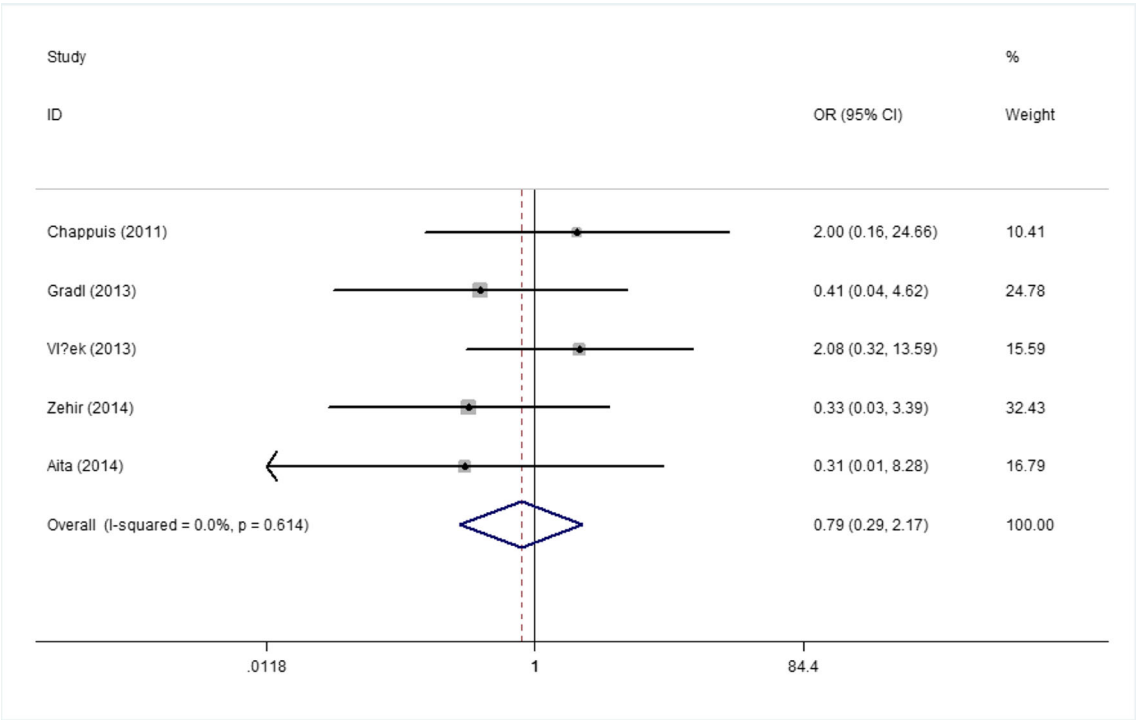
SMD standardized mean difference, *OR* odds ratio, *LL* lower limit, *UL* upper limit, *CI* confidence interval, *CTS* carpal tunnel syndrome, *RNP* radial nerve paraesthesia

[a] Fixed-effects model was performed

[b] Random-effects model was performed

[c] I^2 statistic was defined as the proportion of heterogeneity not due to chance or random error

a) Algodystrophy(pain)



b) Carpal tunnel syndrome **(CTS)**

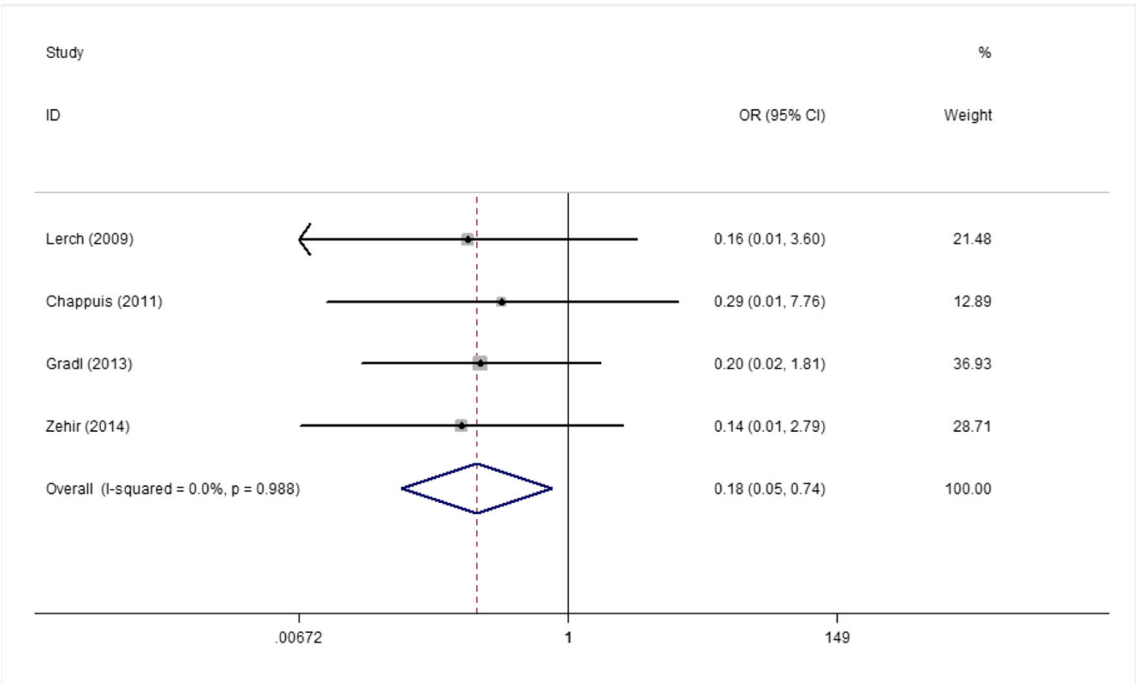
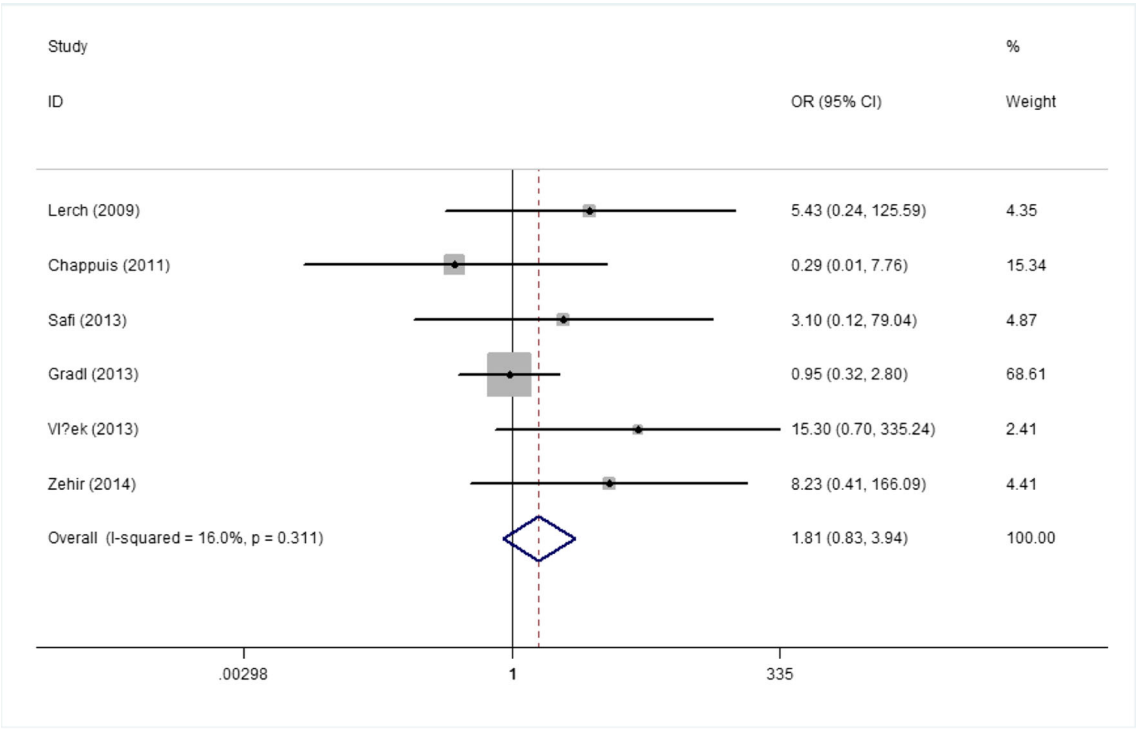


Fig. 2 Forest plots of the meta-analysis comparing variables of (**a**) algodystrophy (pain), (**b**) carpal tunnel syndrome (**CTS**), (**c**) radial nerve paraesthesia and (**d**) tendinous damage between IMN and VLP groups. The width of the *horizontal line* represents the 95% CI of the individual studies, and the *square* represents the proportional weight of each study. The *diamond* represents the pooled OR and 95% CI

articular or simple intra-articular distal radius fractures. Results in this meta-analysis revealed that no significant differences were found between both methods in terms of clinical functional outcomes at the six months, one- and two-years follow-up, except for Mayo wrist score at the six-month follow up [28]. However, at the early post-

c) Radial nerve paraesthesia



d) Tendinous damage

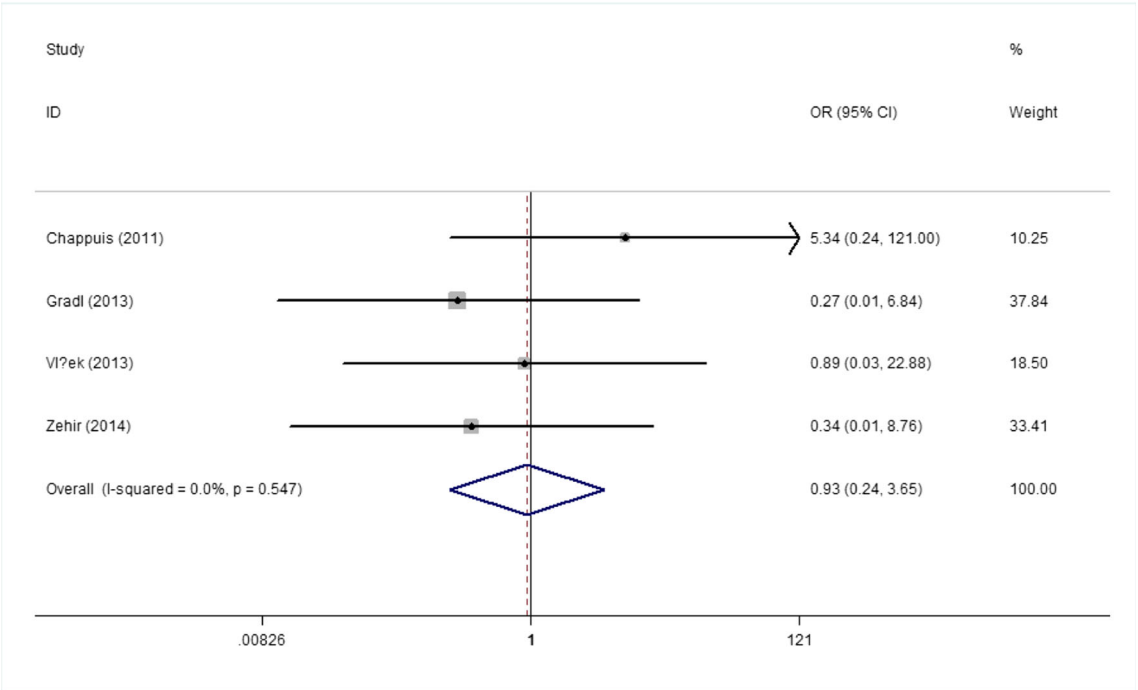


Fig. 2 continued.

operative period (six weeks and three months), IMN had better results than VLP regardless of which function scoring system was used. The carpal tunnel syndrome was the only complication of significance observed in this study, demonstrating the superiority of IMN for treatment of this common injury.

Wang et al. firstly conducted a meta-analysis of RCTs for comparing results between IMN and VLP, but failed to

demonstrate significant superiority in either treatment method [20]. Based on our clinical practice and reported results in literature, patients treated by IMN were more likely to obtain improved early outcomes, which might be neglected by the authors [20] and most surgeons. Based on three RCTs included in his study, we added three studies (two retrospective studies and one RCT) in the present meta-analysis and the pooled results verified our hypothesis. In this meta-analysis, the only result that might affect the test validity was the Mayo score at post-operative six months in the study by Chappuis et al. [28]. In his study, the authors investigated that Mayo score in the VLP group was better than in the IMN group, but we thought this did not affect the final conclusion in this meta-analysis. In his study, the authors applied a dorsal nail fixation of unique design and the approach to the fracture site was different from a traditional small incision over the radial styloid, which might affect the recovery of soft tissue and bone. However, the authors also investigated similar results at six months using the DASH score system, which was consistent with other studies. Therefore, we thought patients treated by IMN could benefit more than VLP at the early post-operative period (≤3 months), which was of particular helpfulness in re-obtaining the confidence of workers with specialized manual skills to return to their prior jobs.

There were no significant differences between both fixations in terms of functional and radiographic parameters and motion range at the post-operative latter follow ups (≥6 months), which was consistent with reported results in most studies. And this is could be explained by the needed time for bony union and soft tissue recovery, because for them six months and more was sufficient if no significant complications developed.

CTS was a most important complication that was associated with VLP. And in this meta-analysis, the pooled incidence was 0.8% in IMN and 8.7% in the VLP group, respectively. As similarly reported in the previous meta-analysis by Wang et al. [20], CTS was the only complication of statistical significance. From our practice, CTS has a high risk of developing after distal radius fractures, regardless of the treatment method. Although routine performance of prophylactic carpal tunnel release after VLP was recommended in some surgeons, its necessity remains controversial. For patients treated by VLP, the reported incidence was higher and therefore more attention should be paid to recognizing the existing CTS related to injury in the pre-operative examination, and haematoma or oedema in post-operative examination [14]. Some authors attributed CTS to the impaired median nerve due to pre-operative trauma and over-retraction during surgery, and therefore recommended a thorough history and physical examination and avoidance of excessive retraction on the median nerve during surgery [33, 34].

The present study suffers from some weaknesses. First, not all the studies included in this meta-analysis were RCTs, which might reduce the test power. As we all know, it is very difficult for surgeons to be blind to the treatment method, and impossible for patients. Even in the RCTs, few studies were designed as double-blind. In this study, we added three studies to the previous meta-analysis with original intention to enlarge the sample size, and the results were almost similar except for the post-operative early-period function scores. Therefore, the retrospective design of two studies included in this meta-analysis did not affect the final conclusion. Second, the types of IMN and VLP applied in studies were varied and the follow-up periods in the studies ranged largely from six weeks to several years. In addition, patients' age and gender distribution, fracture severity and indications for surgery were not consistent with each other in the original studies. Therefore, heterogeneity among studies was inevitable. However, for variables presenting with significant heterogeneity, we performed sensitive analysis and the significance did not alter, indicating the results were robust and the conclusion was reliable. Third, for post-operative functional evaluation, there were only a small number of studies, and only one single one could provide data of standard format, which might lower the test power and requires further studies to verify the conclusion. In fact, in the study by Aita et al. [27] (36 cases, with 18 in each group), the authors demonstrated better result in the IMN group at six weeks, using the DASH scoring system (23.6 vs 36.4). But they could not provide the detailed SD value, so we could not pool this data.

In this meta-analysis, we added three studies (two retrospective non-RCTs and one RCT) to update the knowledge on better choice for treatment of extra or simple intra-articular distal radius fractures between IMN and VLP. The post-operative later period results (>6 months) were comparable between both fixation methods, and this conclusion was similar as the previous meta-analysis. However, in the early post-operative period, patients treated by IMN could gain more quick recovery and did better than those treated by VLP. We believe it is of particular helpfulness in re-obtaining confidence for workers to return to prior jobs, especially for those with specialized manual skills. This conclusion should be treated cautiously because of the limited number of studies and relatively small sample size. More well-designed, prospective studies with large samples are required to confirm this conclusion.

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Authors' contributions Yingze Zhang, Bing Zhang and Hengrui Chang designed the study; Kunlun Yu and Jiangbo Bai followed up the participants and documented the data; Bing Zhang and Guisheng Zhang analyzed and interpreted the data; Bing Zhang, Pan Hu and Xinzhong Shao wrote the manuscript, and Yingze Zhang approved the final version of the manuscript.

Compliance with ethical standards

Conflict of authors' statement All the authors declare that they have no competing interests, and no organization sponsored the research.

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